An Embedded Wi-Fi Controller in a C band Phased Array Antenna

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Abstract

Modern phased array antennas in radar systems are composed of several thousands of transmit/receive modules (TRM), whose correct functioning has remarkable impact on radar performance.

It is therefore of fundamental importance to check and monitor main characteristics of active array components; such actions will permit to verify system performance in real time and, if necessary, suitable actions to guarantee them may be actuated.

The application presented in the first part refers to a particular application of metamaterial structures inside an open waveguide, whose final purpose is to allow radiation in free space with high efficiency within a wideband well below its cut-off frequency; in the latter an useful application of an embedded WiFi Controller of a phased array antenna.

Keywords

Waveguide; TRM; Phased Array; SRR; Wi-Fi System

Introduction

New generation and future evolution of radars require fully active phased array antennas, integrating several and very sophisticated functions.

Complexity of such antennas requires BITE systems capable to check in real time a great amount of parameters and to transfer main data to the related control unit.

In such new radars, one of the core items is constituted by TRMs, whose functioning characteristics affect strongly the overall performance.

Because of their large number in new radar antennas, internal BITEs have to be minimized in order to reduce module recurrent cost and overall system complexity.

The need to monitor and to check in real time several parameters of a large amount of components, taking into account also its mechanical rotation, involves a complex architecture of the array.

The proposed approach to replace a TRM with a proper probe (form and fit with each module) permits to log and to send back fundamental parameters to a remote monitor station via a Wi-Fi standard link and, in this way, many electrical and mechanical constraints are overcome.

The antenna considered in this work is operated in C band and, in order to avoid reciprocal interferences between the radar and Wi-Fi system, sub-band of 2.4 GHz has been selected.

This choice leads to finding a solution that permits a waveguide suited for C band to propagate signals well below its cut-off frequency and also to radiate them in a very efficient way.

Some constraints forced us to pay our attention to use of a proper metamaterial structure inside a radiating element of the array devoted to monitoring purpose.

Description of the Work

Detailed description of activities related to propagation inside a waveguide at frequencies well below its cut-off is referred in. For the sake of clarity, a summary of results is reported below.

Propagation inside the Waveguide

The first phase of study was devoted to analysing the propagation inside a waveguide with a proper metamaterial structure versus changing of some geometric parameters.

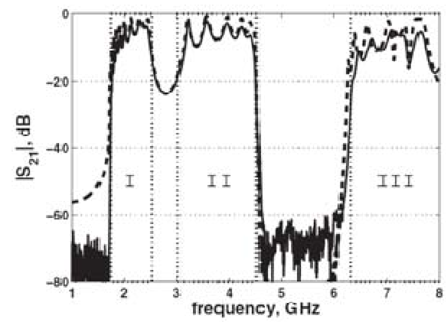

Fig. 1 Transmission for the structure referred in [2] (simulated: dashed – measured: continuous)

In order to validate modelling of metamaterial structures, we analyzed the geometry referred in [2].

The agreement between theoretical results of mod (S_{21}) referred in the paper and those of our simulation - see Fig. 1 and 2- were very good, demonstrating the validity of our model.

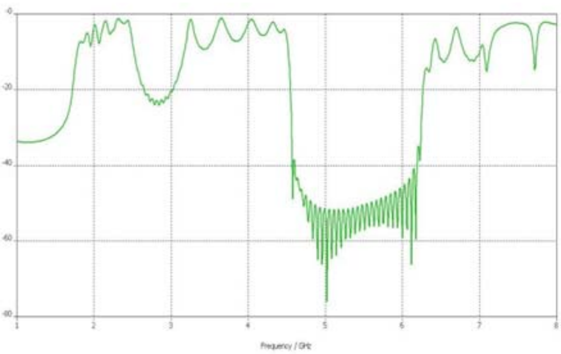

Fig. 2 Transmission simulated with our model

In the second phase of study, we investigated the behaviour of the effective waveguide used in the array in presence of a metamaterial structure like that shown in Fig. 3, a particular configuration of square Split Ring Resonators (SRRs).

The basic configuration analyzed consists of a dielectric slab (Duroid RT 5880, 0.508 mm. thick) with nine cells of square SRRs etched on both sides.

Target of study was to verify possibility to considerably reduce the cut-off frequency from about 4.3 GHz as far as below the 2.4 GHz band.

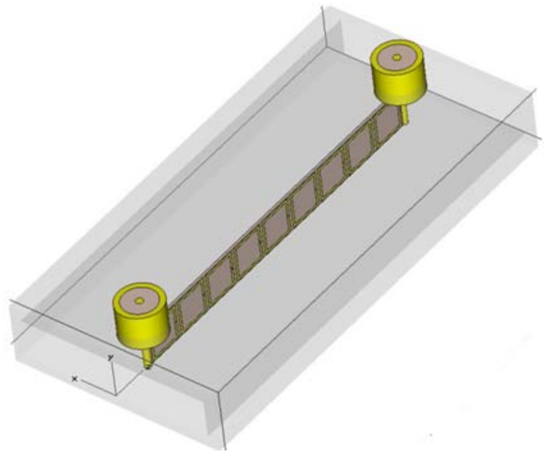

Fig. 3 Base structure used for study of propagation in the given waveguide

Analysis was performed considering different configurations of concentric SRR.

Results revealed that the use of more than 1 SRR in a single cell permits to lower cut-off frequency as far as about 3 GHz; moreover, a sort of "saturation" effect (see Fig. 4) is evident and no appreciable benefit was obtained using more than 3 SRRs.

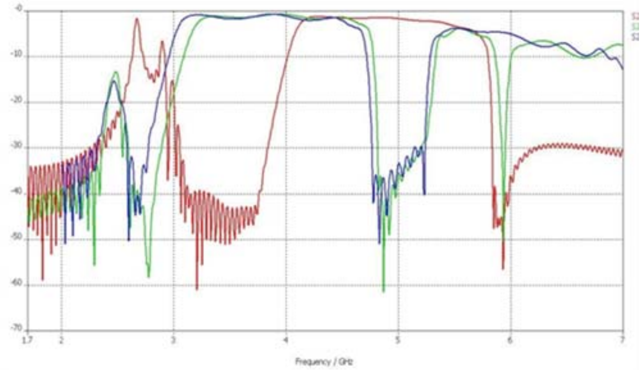

Fig. 4 Slab with 9 cells: transmission vs. number of concentric SRR (red: 1 srr – green: 2 – blue: 3)

Circular split rings configurations have been also analyzed, but better results have been obtained with square rings.

Experimental activity on two samples (the first one constituted by nine cells with only one square SRR – see Fig. 5-; the second with 3 concentric SRRs) demonstrated a good agreement with theory, although little discrepancies due to manufacturing tolerances. – See Fig. 6, related to the more significant sample -.

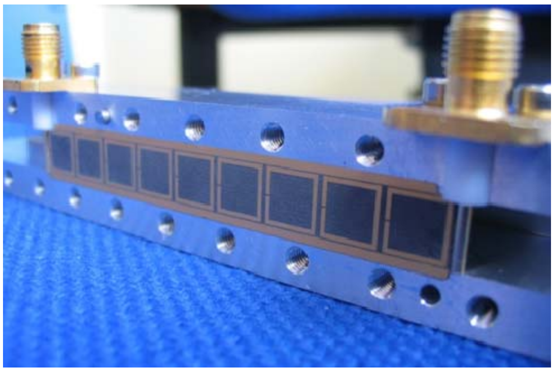

Fig. 5 View of jig used for measurements

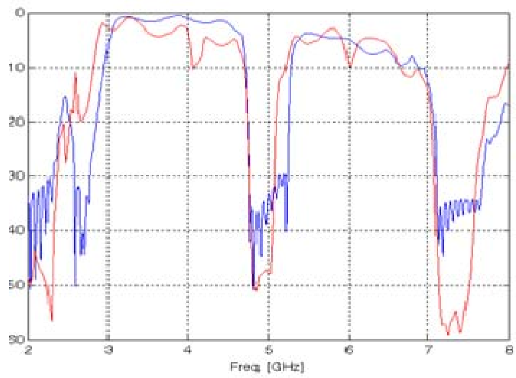

Fig. 6 S_{21} simulated (blue) and measured (red) for slab with 9 cells – 3 SRRs concentric

Despite the lower frequency of the cut-off a little below 3 GHz, the goal to go down below 2.4 GHz was still far and the limit of 2.5 Ghz, with an insertion loss of about -3 dB, seemed to be the lowest achievable,

using only one cell – see Fig. 7.

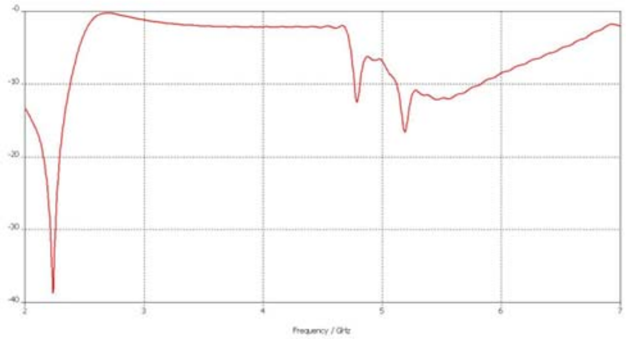

Fig. 7 Slab with only 1 cell – 3 SRRs

Considering the metamaterial inclusion inside the waveguide like a ridge, we realized that, in the same way like in ridged waveguide where the extension of the ridge width permits to lower the cut-off frequency, a similar effect can be obtained introducing more parallel cells (placed side by side).

Simulation confirmed this intuition: in effect, use of several parallel slabs, permitted a further lowering cut-off frequency, as requested, as shown in Fig. 8.

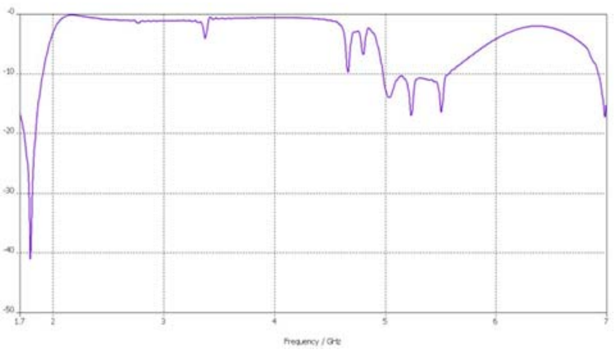

Fig. 8 Waveguide with 3 slabs, single cell and 3 SRRs

Radiation of the Waveguide

In the next step we paid attention to the capability to obtain an efficient radiation from the waveguide loaded with the selected material structure.

Studies performed by some authors [4] for a waveguide with Mu-NeGative (MNG) inclusions (SRRs), reported a poor return loss, narrow operating bandwidth, very low radiation efficiency and, consequently, very poor gain (< 0 dBi), see Fig. 9).

Meanwhile, the initial structure with 3 slabs (1 cell and 3 concentric SRRs revealed to be poor: very narrow band, resonance below 2.4 GHz (~ 1.93 GHz), acceptable return loss and very poor gain (~ - 6 dBi).

It can be summarized that the desired goals are very closed as the actions that permitted to obtain interesting results:

- adjustment of pin height and position of short circuit (that was added as tuning element)
- addition of other surrounding waveguides like in true conditions (they act as a ground-plane that reduce back-scattering and increase gain to the forward half-space)
- some changes concerning the metamaterial structures (innovative solutions are beeing filed for for patent)

The best result concerning return loss and pattern is shown in Figs 9 and 10 respectively.

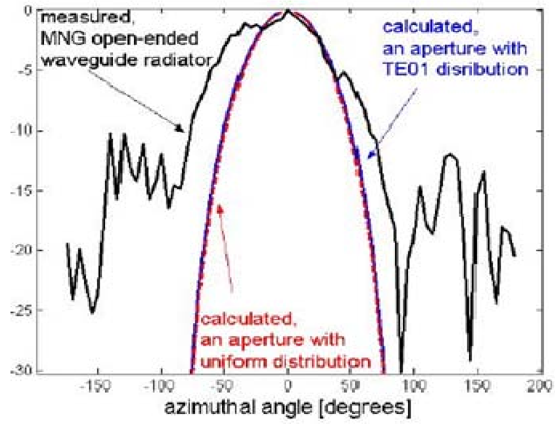

Fig. 9 Measured vs Calculated Radiated Pattern

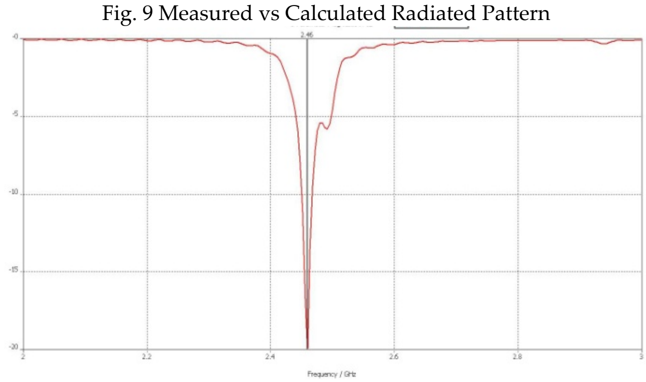

Fig. 10 Return Loss of enhanced waveguide

In particular, relatively to gain and efficiency, it is remarked that the waveguide alone, had an efficiency about 85% and a gain of about +3dBi; instead, with other surrounding waveguide (see a sketch of our antenna in Fig. 11) the efficiency was about 80% and gain about 5.5 dBi.

As reported in Fig. , each module is allocated in the array; the high number of signals, the high number of modules and their complexity would require a control system quite complex and cumbersome to implement the given constraints electromechanical. In addition, because of vibrations and oscillations, the behaviour of the system itself may be different in the static condition (antenna in stand mode) from the dynamic (antenna in rotating mode). Based on an innovative technique that allows us to replace TRM by a plug

approach, each TRM is easily replaceable by a Wireless Probe.

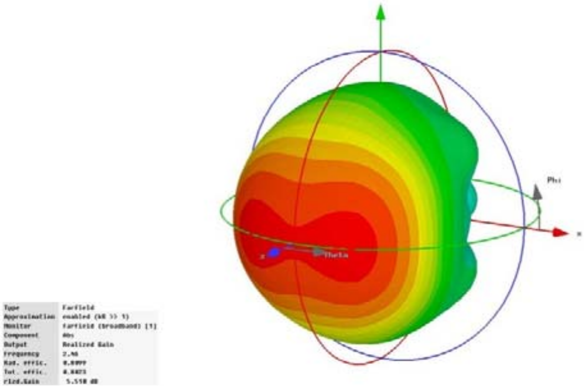

Fig. 11 Radiation pattern of enhanced waveguide

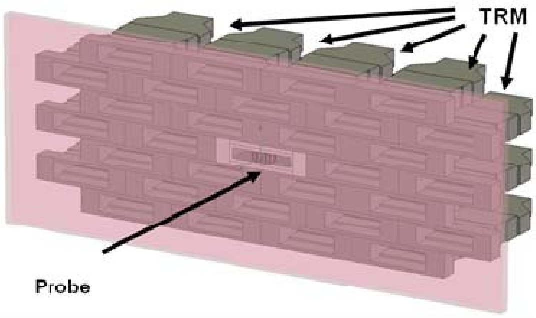

Fig. 12 C Band Active Phase Array

Bandwidth Broadening

This target was equally challenging as the others and the actions performed to obtain the first interesting results were aimed to achieve multiple resonances inside the structure, i.e. acting on the SRR's geometry and configuration.

Some preliminary simulations revealed a promising way rotating some SRR's around the axis orthogonal to the plane containing the rins by 90°, other by a rotation of 180° and others by a rotation of 270°.

An intense experimental activity demonstrated the validity of such actions, and in addition to the preliminary simulations, we found some improvements sticking on a symmetric pair of SRR's.

The trend of bandwidth broadening is demonstrated in Fig. 13. Here, the first curve is related to the initial condition (all SRR's in the same identical configuration); the second curve reveals a double resonance and therefore a bandwidth can be broadened.

Activity to improve these results is in progress, in particular to obtain a better impedance matching within the operating frequency band and to better control the resonances so that the bandwidth can be widened.

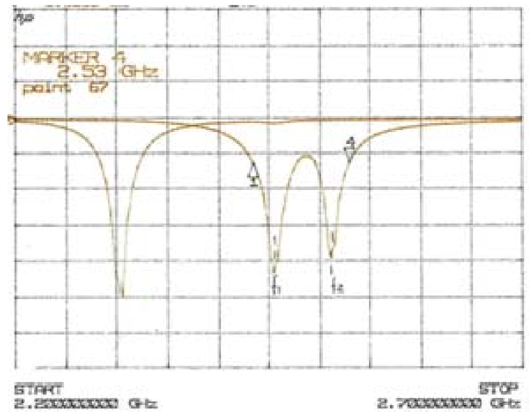

Fig. 13 Preliminary results related to bandwidth broadening

Wireless Probe

The main purpose of these probes is to monitor the power and timing signal further than data for the phases and the attenuation setting. Due to the restriction of space between the modules TRM, it is impossible to accommodate additional connectors to implement such off-line and on-line checks. When all rows are positioned on the antenna, if you detect anything wrong during the test activities, you need to check the status of power supply modules namely if they are driven as required and if they are properly fed with RF. Currently a partial control circuits is run by using BITE ("Built In Test Equipment") whose signals are appropriately processed and sent to the remote via sliding contacts or "slip ring". In contrast, the architecture would be more complicated and more difficult to implement of the proposed solution, also considering more in details the various monitor and control signals as temperature value, calibration status, presence of RF, the power supply, etc.

To overcome the various problems encountered, it is seen that the optimal solution is to replace a module TRM operating with a test module (module "probe") which can be transmitted via radio link to a digital measuring station "master ". The state of the bus signals controls the temperature, calibration status, the presence of RF and power connectors on the present.

Radiolink between the Array Under Test and the Fixed Base Station works in 2, 4 GHz Wi-Fi band.

The same probe (see Fig. 14) able to show by several 7 segments displays the last control data and the status of fundamental power supplies voltages by LED.

Base Station

The Base Station can manage several Wireless Probes, each for a different raw. It is composed of several antenna disposed on fixed part in order to cover all direction during rotating mode and a WiFi Controller.

Fig. 14 Wireless Probe Prototype

Based on a defined protocol, it is possible to ask for Wireless Status Probe in order to collect information relevant to the temperature in the row, the level of the power, the Trasmit/ Receive Trigger and the trigger of commands on-going.

The main status information is shown on Control Panel, one for each Wireless Probe, see Fig. 15, where the main status information are graphically shown: very useful, the information about the temperatures and the reconstructed graph of Trigger signals. All data are digitally captured by the probe, also by a memory buffers, and transmitted by the wireless link on demand from the Fixed Base Control Panel.

In this way, an easily remote control is also possible during the antenna rotation when the use of cables is impossible.

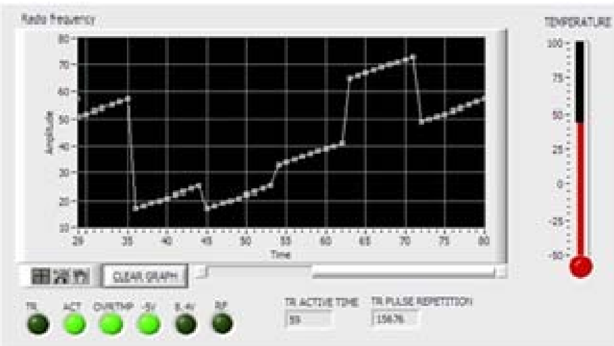

Fig. 15 Fixed Base Control Panel

Conclusions

Use of MNG structures, according to results of several works, demonstrated capability to permit propagation below the typical cut-off frequency of a waveguide.

An interesting result of this work reveals that physical limit for the minimum achievable frequency may be lowered by use of various MNG structure placed side by side.

Radiation characteristics of a waveguide filled with a MNG structure are demonstrated to be very poor having a gain lower than 0 dBi and very low radiation efficiency -.

Another interesting result obtained in this work is the possibility to improve such characteristics, leading to good efficiency and gain; as well as activities to widen bandwidth are still in progress with excellent results.

The achievement of proposed objectives shall allow embedding a monitoring system, based on Wi-Fi standard link at 2.4 GHz, in a phased array aperture constituted by waveguide elements operating at higher frequencies.

Use of one of the array elements, for link with a remote monitor station, will permit to overcome some critical constraints to carry out a deeper monitoring, with the benefit to improve some capabilities of modern active radars.

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Maurizio Cicolani was born in Rome, Italy. He received the Laurea degree in electronic engineering from the University of Rome "La Sapienza" with a thesis on the coplanar waveguide. He joined in Selenia, Alenia Marconi Systems now Selex-SI (a Finmeccanica company), since 1985. From 1985 to 1998 he was a RF designer in the microwave department, where he developed important passive and active components for antenna systems. His main activities were in the design of Solid State Transmitters and Amplifiers, state of the art TRM, Network distributor for Active Antennas and Radar subassemblies. From 1998 to 2001 he was the Head of Microwave Department, where he finalised important programs on AESA and Solid State Radars. From 2001 to 2009 he was the Director of Research & Development Labs of Selex-SI where he was responsible for strategic programs on New Active Antennas, low cost TRM and MMICs devices developed and manufactured within an internal GaAs foundry. He was the manager of Antenna, Microwave, GaAs foundry, Microelectronic, Photonic and Rx departments. The main activities were dedicated to important R&D programs as GaN-GaAs devices, photonic components, TRM and advanced AESA radars. He is currently a Senior Vice President and the Director Quality Assurance & Business Improvement. Currently he is the SVP of the Selex Sistemi Integrati as responsible for Quality Assurance and IT Division. He is a member of IEEE MTT Society and Council Scientific member of SIEM, and Chairman of 2009 EUMC. He has authored or co-authored of several scientific and technical publications on microwave, antenna and radar systems.

Angelo De Luca was born in Rome, Italy, on November 15, 1951. He received the Laurea degree (cum laude) in electronic engineering from "La Sapienza", University of Rome, Rome, Italy in 1976.
From 1977 up to 1985 he worked at the antennas dept of Selenia S.p.A., Rome, Italy as an Antenna Designer. During this period he gained good experience in the field of antennas for radar and missile systems.
In 1985 he joined the antennas dept of ELETTRONICA S.p.A., Rome, Italy where he worked as senior Antenna Designer up to 2006. During this period he has developed considerable expertise on wideband and ultra-wideband antennas for electronic countermeasures systems, working in numerous national projects and also in several international projects in partnership. From 2006 up to 2010 he worked in SELEX Sistemi Integrati, Rome, Italy as head of antennas dept. At present time he works as consultant on behalf of some companies and he is involved in the design of antennas for particular applications in telecommunication systems.

Mario Teglia was born in Civitavecchia, Rome, Italy, on February 11, 1959. He received the B.Eng. and the M.Sc. degrees from La Sapienza University of Rome, Rome, Italy, in 1989 (Summa cum Laude).
Since 1989, he has been working at Selex-Sistemi Integrati where now has been the Development of Systems Vice President.
He started his career as Hardware and Software designer on Digital Signal Processing algorithms and their implementation by microprocessor and dedicated hardware with applications to passive and active phased array antennas for radar systems, then he worked in numerous national projects and also in several international projects in partnership as project leader.
Dr. Teglia is a Registered Professional Engineer, with the order of Engineers of Italy.